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Wang et al.

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(54) **ALMOST-BLANK SUBFRAME CONFIGURATION DETECTION IN HETEROGENEOUS NETWORKS**

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USPC 370/252, 279; 375/267, 295, 340
See application file for complete search history.

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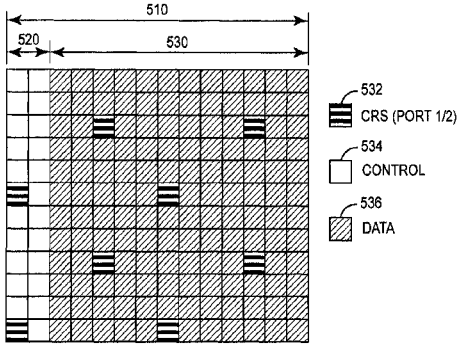
(57) **ABSTRACT**

A method for detecting an Almost-Blank Subframe (ABS) configuration for an interfering macro cell of a heterogeneous network is implemented in a wireless terminal. For one or more resource blocks in a received signal, a first power metric is calculated as a function of channel response estimates determined for predicted cell-specific (or common) reference signal (CRS) resource element locations in a plurality of symbols. For the one or more resource blocks in the received signal, a second power metric is calculated as a function of channel response estimates determined for the predicted CRS resource element locations in a single one of the plurality of symbols. A difference between the first and second power metrics is compared to a threshold, and responsive to the comparison a determination is made as to whether the macro cell is operating in a Multicast and Broadcast Single Frequency Network (MBSFN) mode or a non-MBSFN mode.

16 Claims, 11 Drawing Sheets



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H04L 27/26	(2006.01)
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H04W 52/00	(2009.01)
H04W 72/00	(2009.01)

(52) **U.S. Cl.**

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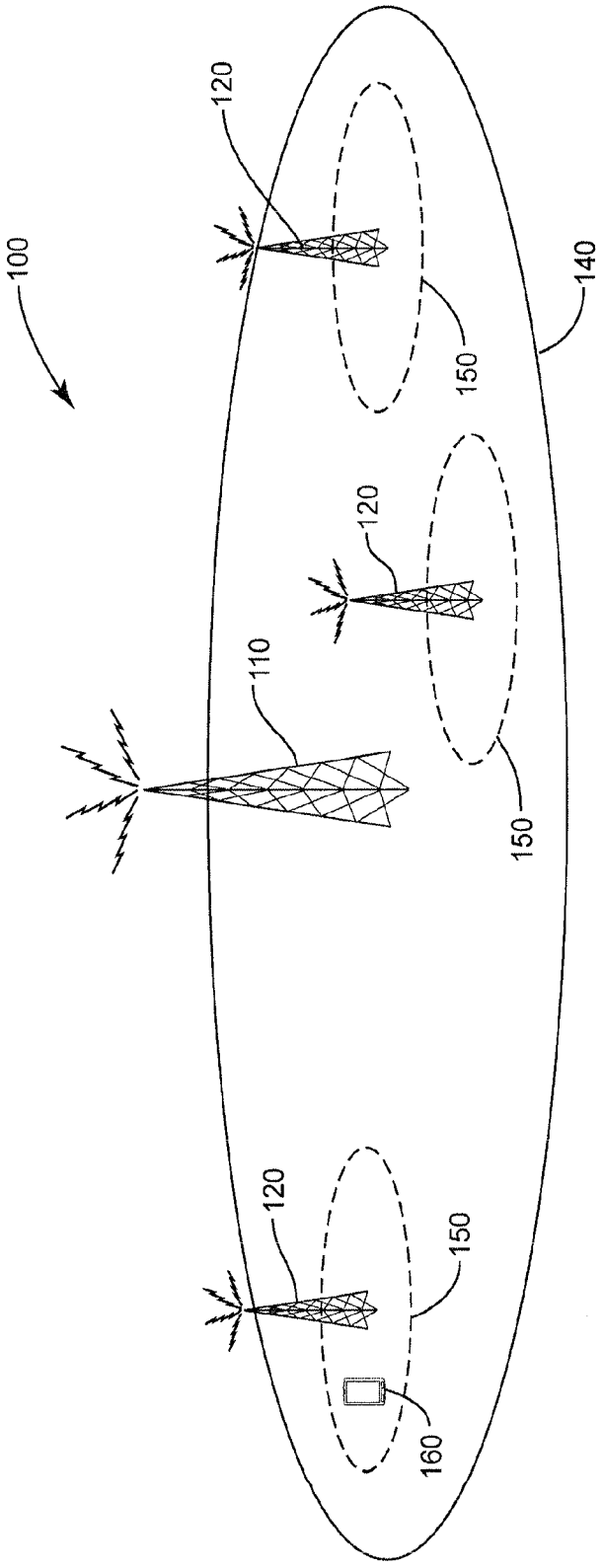


FIG. 1
(PRIOR ART)

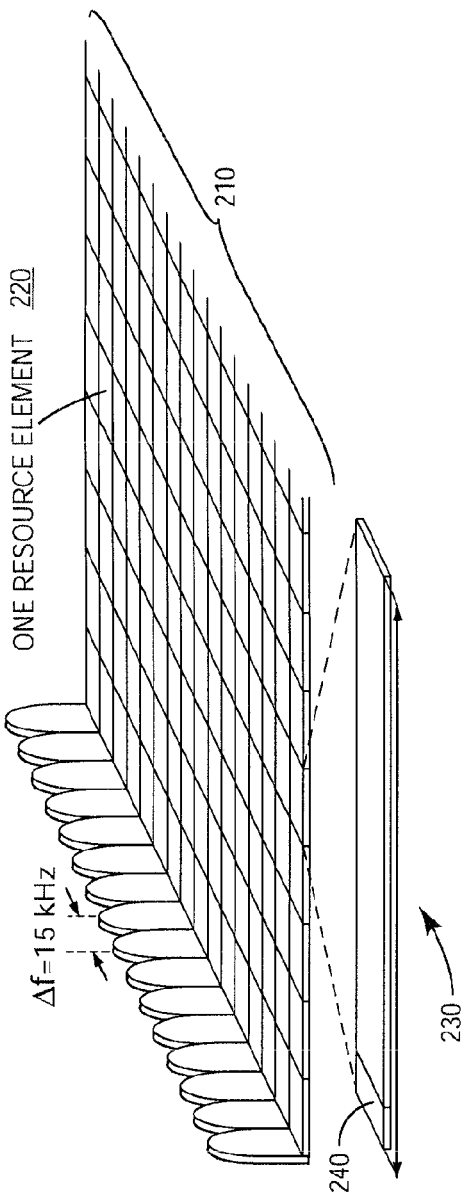


FIG. 2
(PRIOR ART)

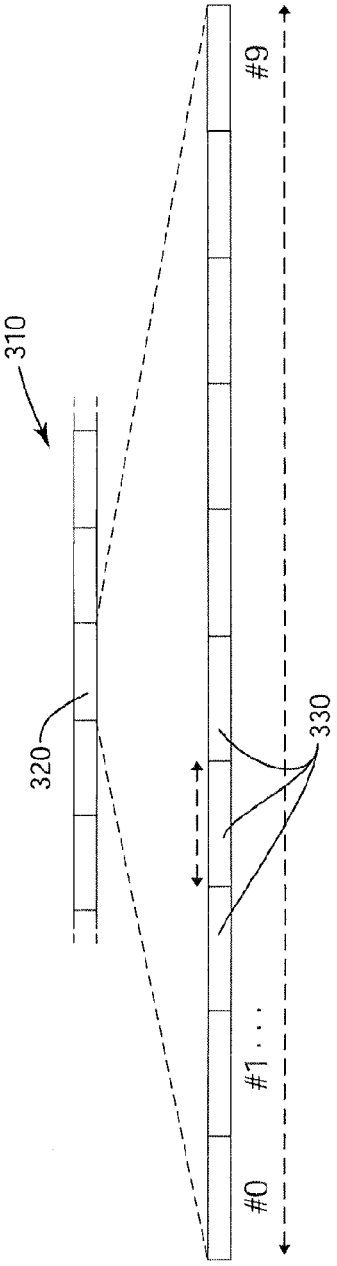


FIG. 3
(PRIOR ART)

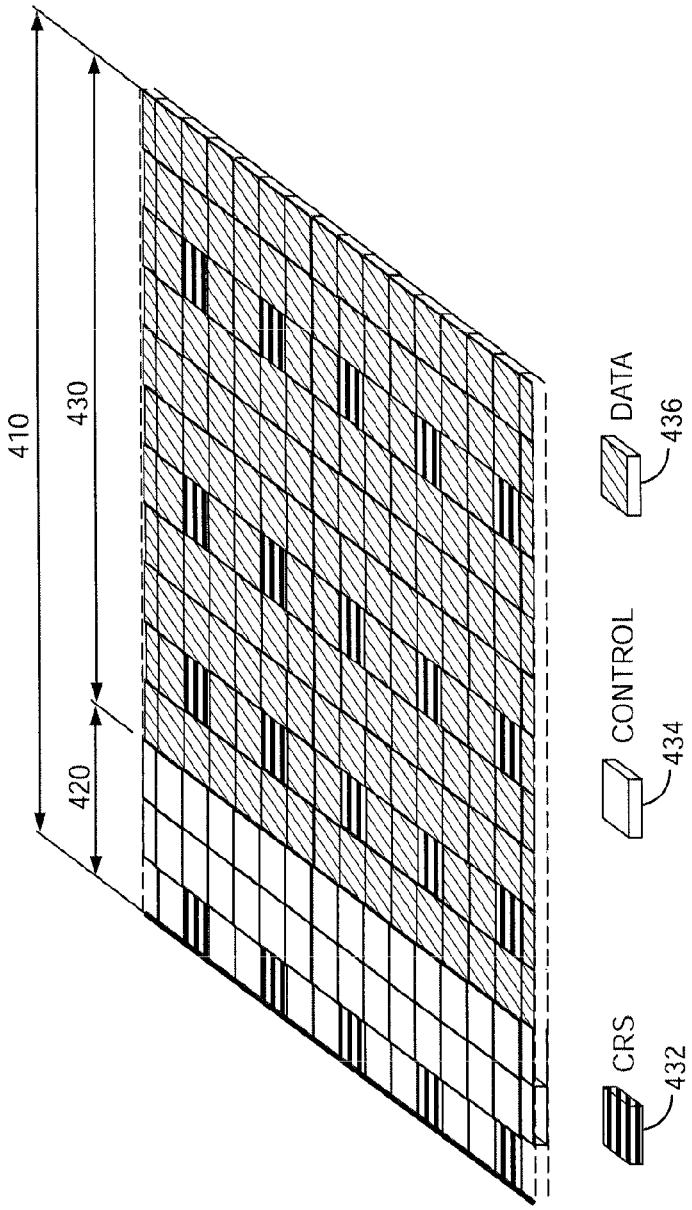


FIG. 4
(PRIOR ART)

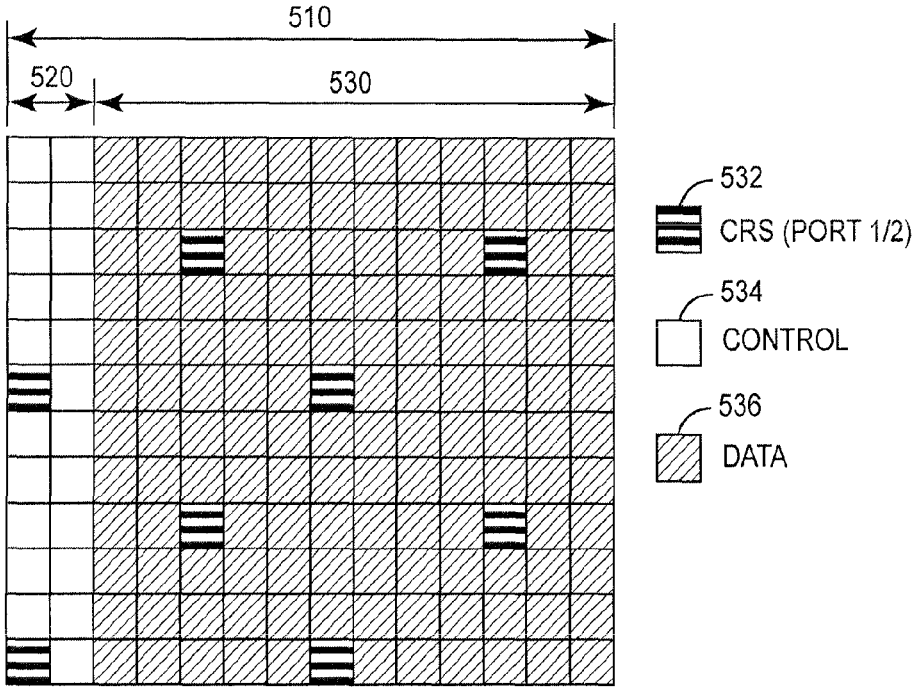

510
520
530
532
CRS (PORT 1/2)
534
CONTROL
536
DATA

FIG. 5A

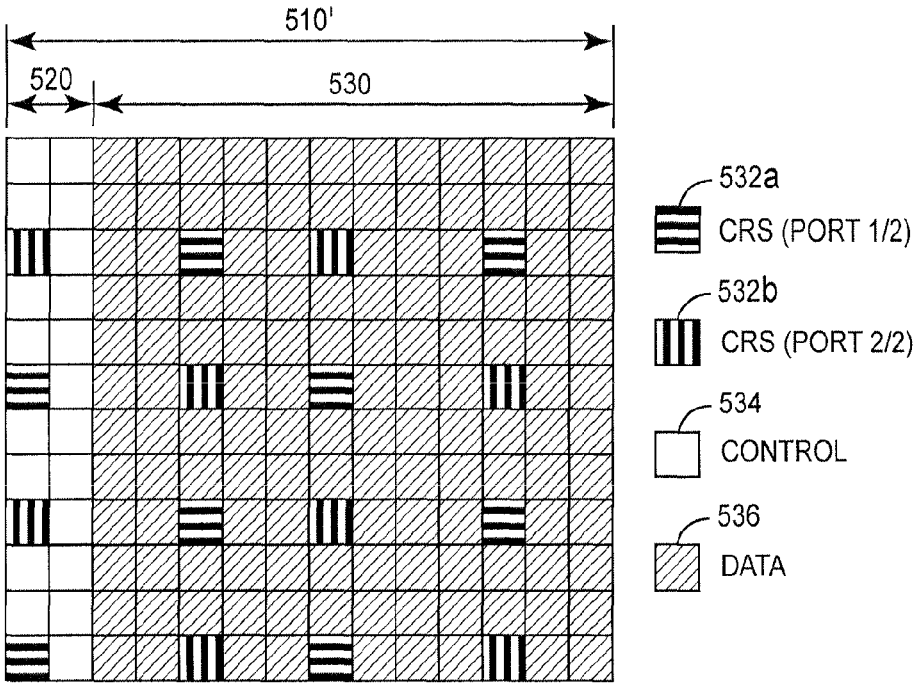
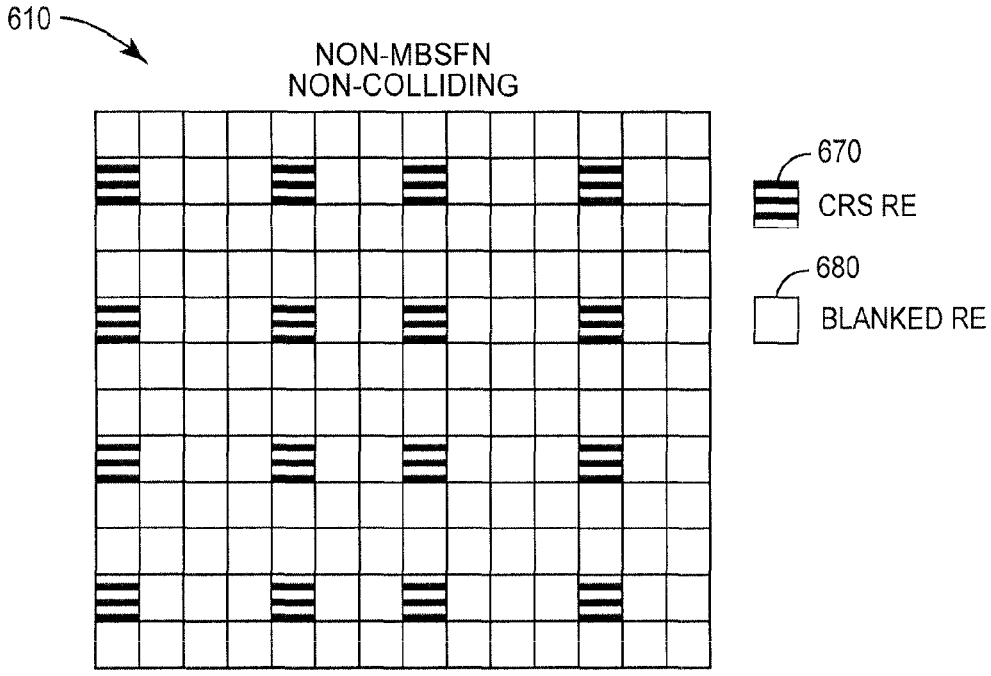
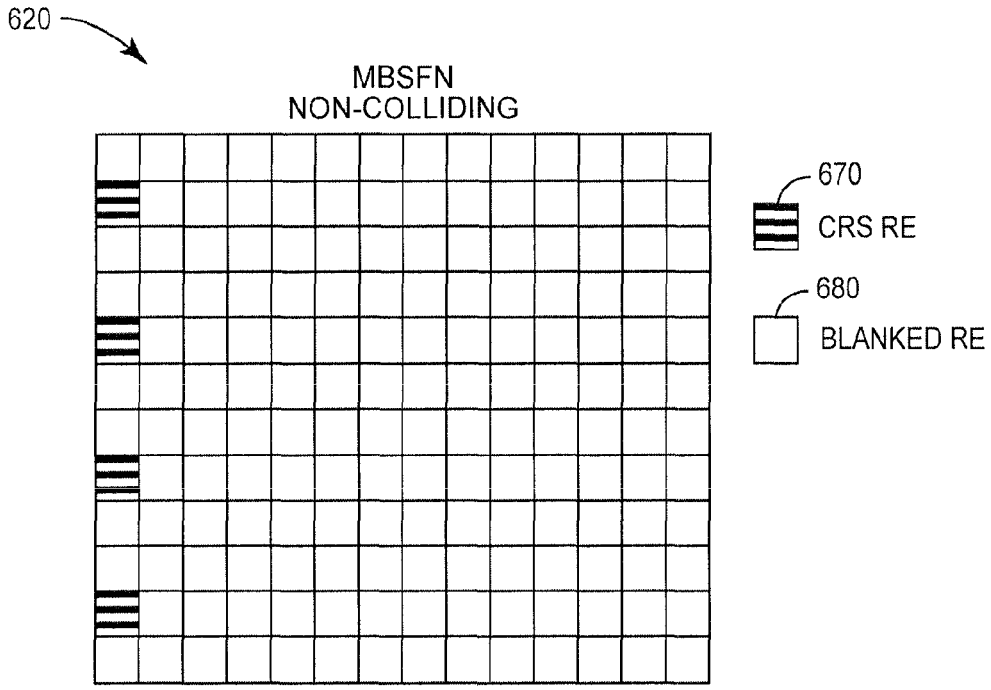

510'
520
530
532a
CRS (PORT 1/2)
532b
CRS (PORT 2/2)
534
CONTROL
536
DATA

FIG. 5B



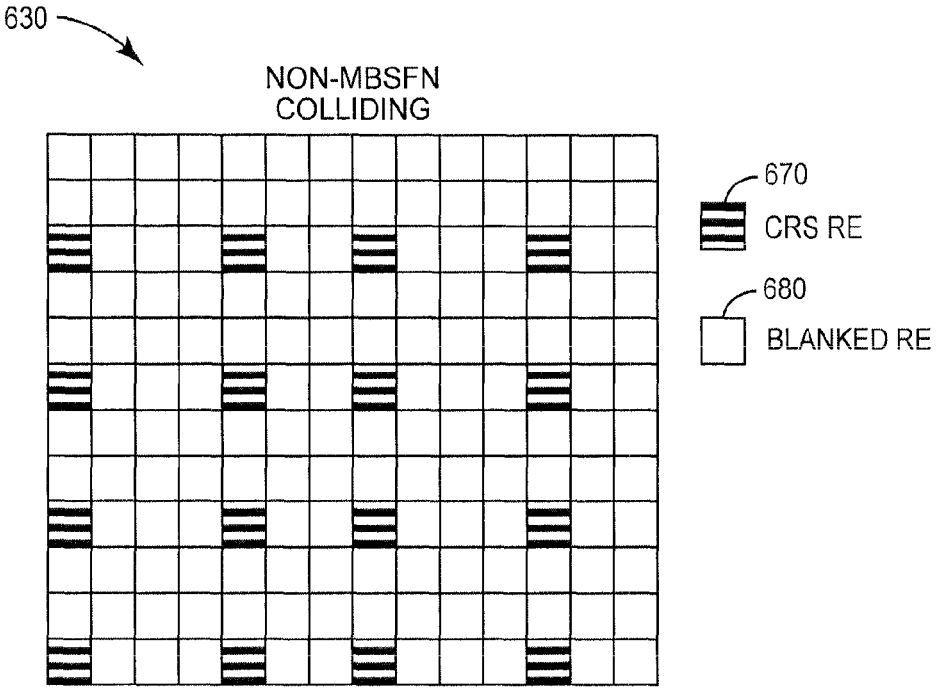
(A) SCENARIO 1: NON-COLLIDING CRS REs WITH NON-MBSFN ABS CONFIGURATION

FIG. 6A



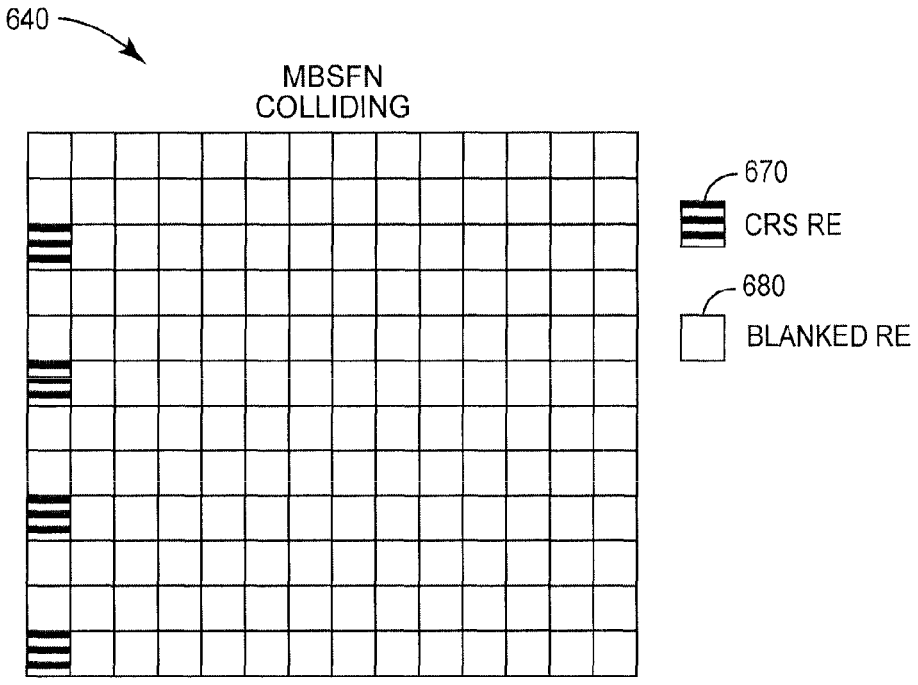
(B) SCENARIO 2: NON-COLLIDING CRS REs WITH MBSFN ABS CONFIGURATION

FIG. 6B



(C) SCENARIO 3: COLLIDING CRS REs WITH NON-MBSFN ABS CONFIGURATION

FIG. 6C



(D) SCENARIO 4: COLLIDING CRS REs WITH MBSFN ABS CONFIGURATION

FIG. 6D

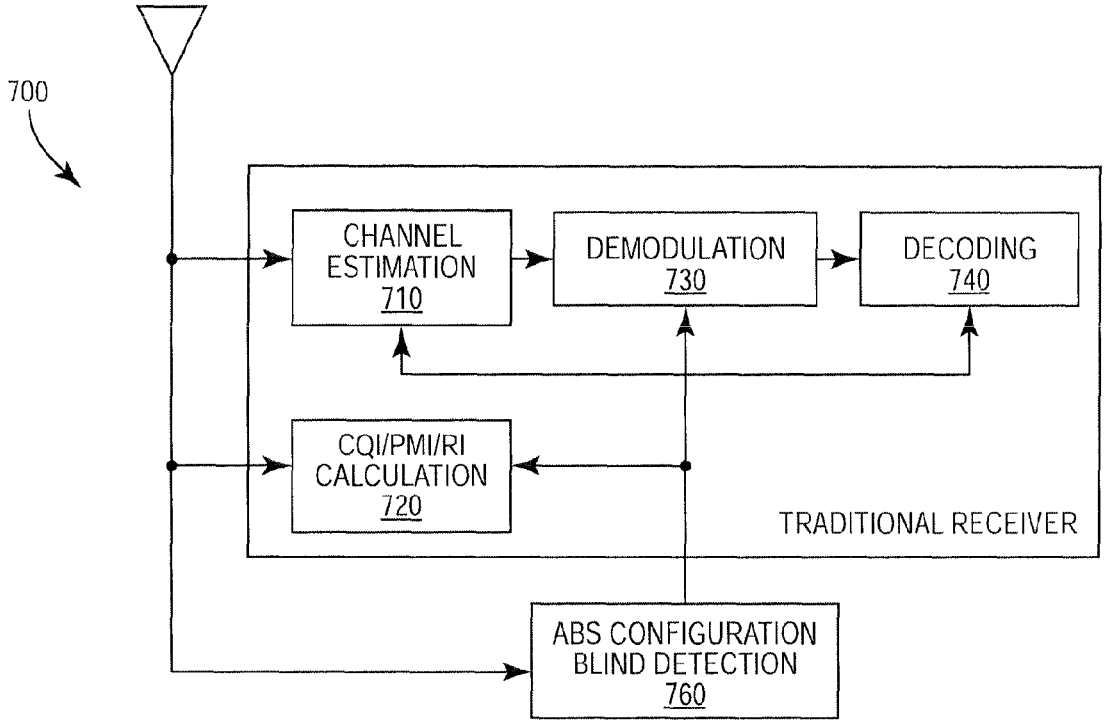

700
CHANNEL ESTIMATION 710
DEMODULATION 730
DECODING 740
CQI/PMI/RI CALCULATION 720
TRADITIONAL RECEIVER
ABS CONFIGURATION BLIND DETECTION 760

FIG. 7

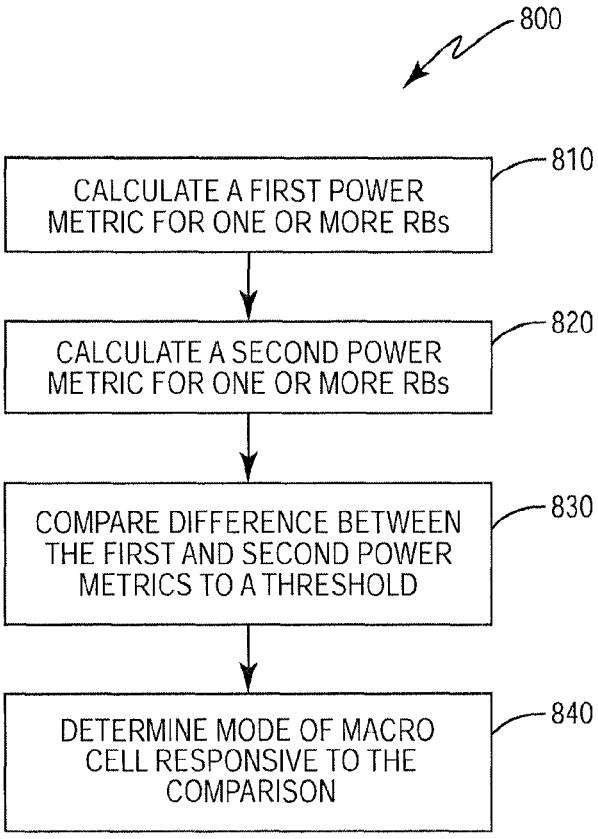

800
CALCULATE A FIRST POWER METRIC FOR ONE OR MORE RBs
810
CALCULATE A SECOND POWER METRIC FOR ONE OR MORE RBs
820
COMPARE DIFFERENCE BETWEEN THE FIRST AND SECOND POWER METRICS TO A THRESHOLD
830
DETERMINE MODE OF MACRO CELL RESPONSIVE TO THE COMPARISON
840

FIG. 8

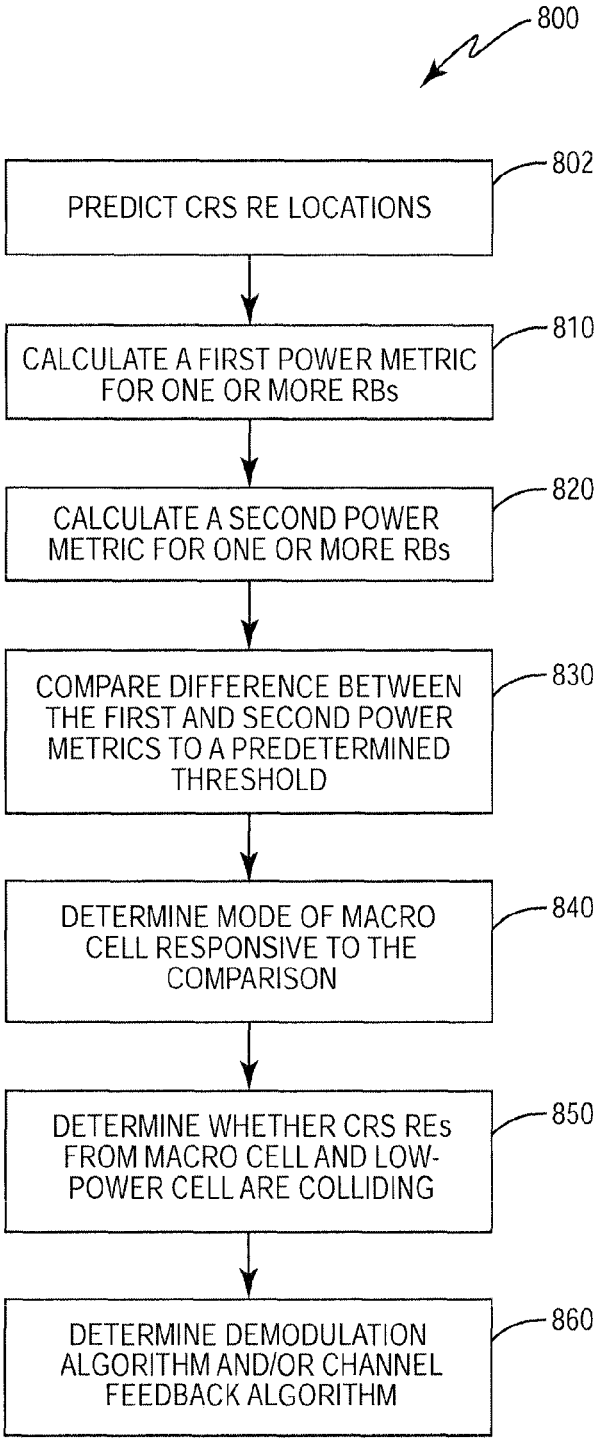

800
PREDICT CRS RE LOCATIONS
802
CALCULATE A FIRST POWER METRIC FOR ONE OR MORE RBs
810
CALCULATE A SECOND POWER METRIC FOR ONE OR MORE RBs
820
COMPARE DIFFERENCE BETWEEN THE FIRST AND SECOND POWER METRICS TO A PREDETERMINED THRESHOLD
830
DETERMINE MODE OF MACRO CELL RESPONSIVE TO THE COMPARISON
840
DETERMINE WHETHER CRS REs FROM MACRO CELL AND LOW-POWER CELL ARE COLLIDING
850
DETERMINE DEMODULATION ALGORITHM AND/OR CHANNEL FEEDBACK ALGORITHM
860

FIG. 9

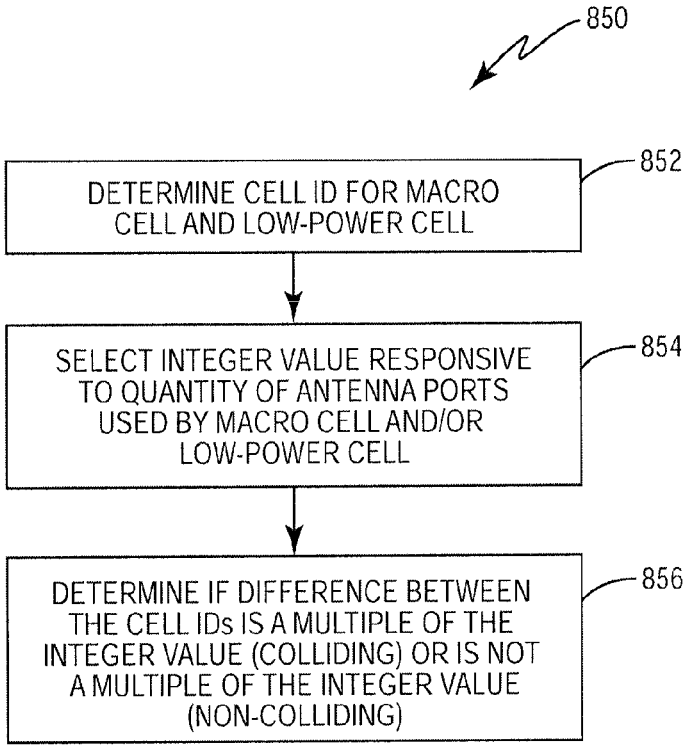

850
DETERMINE CELL ID FOR MACRO CELL AND LOW-POWER CELL
852
SELECT INTEGER VALUE RESPONSIVE TO QUANTITY OF ANTENNA PORTS USED BY MACRO CELL AND/OR LOW-POWER CELL
854
DETERMINE IF DIFFERENCE BETWEEN THE CELL IDs IS A MULTIPLE OF THE INTEGER VALUE (COLLIDING) OR IS NOT A MULTIPLE OF THE INTEGER VALUE (NON-COLLIDING)
856

FIG. 10

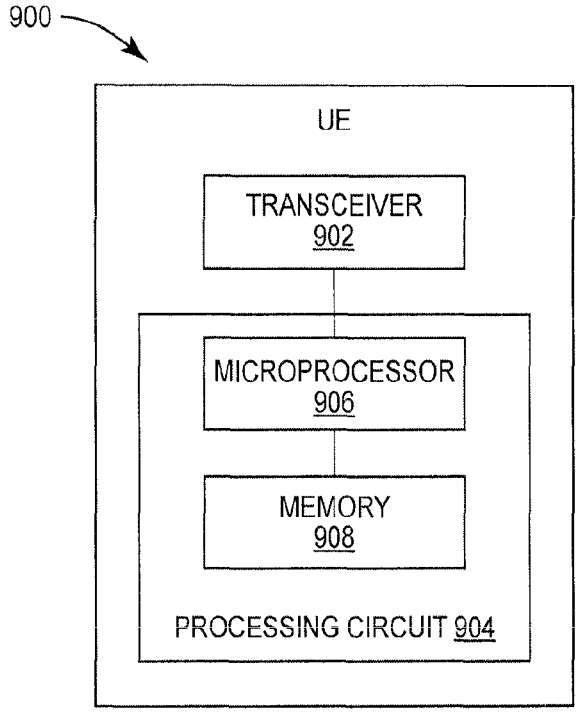

900
UE
TRANSCEIVER
902
MICROPROCESSOR
906
MEMORY
908
PROCESSING CIRCUIT 904

FIG. 11

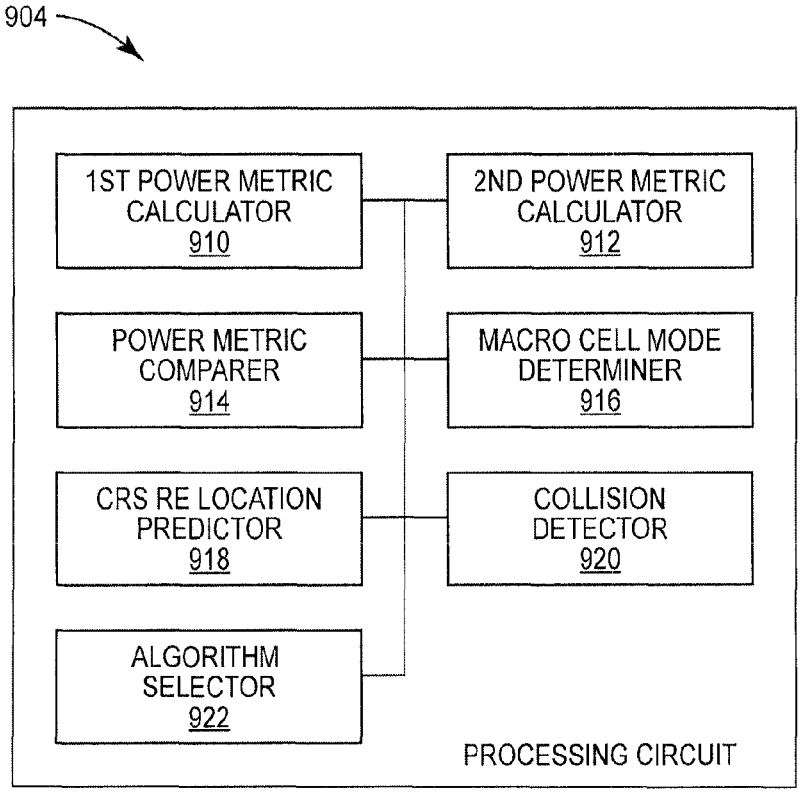

904
1ST POWER METRIC CALCULATOR
910
2ND POWER METRIC CALCULATOR
912
POWER METRIC COMPARER
914
MACRO CELL MODE DETERMINER
916
CRS RE LOCATION PREDICTOR
918
COLLISION DETECTOR
920
ALGORITHM SELECTOR
922
PROCESSING CIRCUIT

FIG. 12

ALMOST-BLANK SUBFRAME CONFIGURATION DETECTION IN HETEROGENEOUS NETWORKS

TECHNICAL FIELD

The present invention relates generally to heterogeneous wireless communication networks, and more particularly relates to techniques for determining an Almost-Blank Subframe (ABS) configuration of a macro cell in a heterogeneous network.

BACKGROUND

The 3rd Generation Partnership Project (3GPP) is continuing development of the fourth-generation wireless network technologies known as Long-Term Evolution (LTE). In heterogeneous networks, a mixture of cells of different sizes and overlapping coverage areas are deployed. Improved support for heterogeneous network operations is part of the ongoing specification of 3GPP LTE Release-10, and improved support and further improvements in the context of new features for heterogeneous network operations are being discussed for Release-11 and beyond.

One example of such a deployment is seen in the heterogeneous network **100** of FIG. **1**, where several low-power cells **120** (e.g. picocells), each with a respective coverage area **150**, are deployed within the larger coverage area **140** of a macro cell **110**, for supporting wireless communication with one or more wireless terminals **160**. The macro cell **110** corresponds to a macro-base station, or node B, ("MeNB"), while the picocells **120** correspond to pico base stations ("PeNBs"). The network **100** of FIG. **1** is suggestive of a wide-area wireless network deployment. Some additional examples of low-power nodes, also referred to as "points," in heterogeneous networks, include home base stations and relays. Although picocells are discussed throughout this application, it is understood that these are only a non-limiting example of the type of low-power cell that can be used in a heterogeneous network.

One aim of deploying low-power nodes such as picocells **120** within the macro coverage area **140** is to improve system capacity, by means of cell-splitting gains. In addition to improving overall system capacity, this approach also allows users to be provided with a wide-area experience of very-high-speed data access, throughout the network. Heterogeneous deployments are particularly effective for covering traffic hotspots, i.e., small geographical areas with high user densities. These areas can be served by picocells, for example, as an alternative deployment to a denser macro network.

Orthogonal Frequency-Division Multiplexing (OFDM) technology is a key underlying component of LTE. As is well known to those skilled in the art, OFDM is a digital multi-carrier modulation scheme employing a large number of closely-spaced orthogonal sub-carriers. Each sub-carrier is separately modulated using conventional modulation techniques and channel coding schemes. In particular, 3GPP has specified Orthogonal Frequency-Division Multiple Access (OFDMA) for the downlink transmissions from the base station to a wireless terminal, and has specified Single Carrier Frequency-Division Multiple Access (SC-FDMA) for uplink transmissions from a wireless terminal to a base station. Both multiple access schemes permit the available sub-carriers to be allocated among several users.

SC-FDMA technology employs specially formed OFDM signals, and is therefore often called "pre-coded OFDM" or

Discrete-Fourier-Transform (DFT)-spread OFDM. Although similar in many respects to conventional OFDMA technology, SC-FDMA signals offer a reduced peak-to-average power ratio (PAPR) compared to OFDMA signals, thus allowing transmitter power amplifiers to be operated more efficiently. This in turn facilitates more efficient usage of a wireless terminal's limited battery resources. (SC-FDMA is described more fully in Myung, et al., "Single Carrier FDMA for Uplink Wireless Transmission," *IEEE Vehicular Technology Magazine*, vol. 1, no. 3, September 2006, pp. 30-38.)

The basic LTE physical resource can be seen as a time-frequency grid. This concept is illustrated in FIG. **2**, which shows a number of so-called "subcarriers" in the frequency domain, at a frequency spacing of Δf, divided into OFDM symbol intervals in the time domain. Each individual element of the resource grid **210** is called a resource element (RE) **220**, and corresponds to one subcarrier during one OFDM symbol interval, on a given antenna port. One of the unique aspects of OFDM is that each symbol **230** begins with a cyclic prefix **240**, which is essentially a reproduction of the last portion of the symbol **230** affixed to the beginning. This feature minimizes problems from multipath, over a wide range of radio signal environments. Although reference numeral **230** points to a single RE of an OFDM symbol, it is understood that reference numeral **230** refers to the entire OFDM symbol and not just that single RE.

In the time domain, LTE downlink transmissions are organized into radio frames of ten milliseconds each, each radio frame consisting of ten equally-sized subframes of one millisecond duration. This is illustrated in FIG. **3**, where an LTE signal **310** includes several frames **320**, each of which is divided into ten subframes **330**. Not shown in FIG. **3** is that each subframe **330** is further divided into two slots, each of which is 0.5 milliseconds in duration.

LTE link resources are organized into "resource blocks," often defined as time-frequency blocks with a duration of 0.5 milliseconds, corresponding to one slot, and encompassing a bandwidth of 180 kHz, corresponding to 12 contiguous subcarriers with a spacing of 15 kHz. Resource blocks are numbered in the frequency domain, starting with 0 from one end of the system bandwidth. Two time-consecutive resource blocks represent a resource block pair, and correspond to the time interval upon which scheduling operates. Of course, the exact definition of a resource block may vary between LTE and similar systems, and the inventive methods and apparatus described herein are not limited to the numbers used herein. Thus, although the term "resource block" is used below to refer to a block of resources covering **12** consecutive subcarriers with a duration of 1 millisecond (a 12×14 resource block) instead of a duration of 0.5 milliseconds (a 12×7 resource block), it is understood that this is only a non-limiting example.

In general, resource blocks may be dynamically assigned to wireless terminals, and may be assigned independently for the uplink and the downlink. Depending on a wireless terminal's data throughput needs, the system resources allocated to it may be increased by allocating resource blocks across several sub-frames, or across several frequency blocks, or both. Thus, the instantaneous bandwidth allocated to a wireless terminal in a scheduling process may be dynamically adapted to respond to changing conditions.

For scheduling of downlink data, the base station transmits control information in each subframe. This control information identifies the wireless terminals to which data is targeted and the resource blocks, in the current downlink subframe, that are carrying the data for each terminal. The first one, two, three, or four OFDM symbols in each subframe are used to

carry this control signaling, and may be referred to as a "control region." In FIG. **4**, a downlink subframe **410** is shown, with three OFDM symbols allocated to control region **420**. The control region **420** consists primarily of control data resource elements (REs) **434**, but also includes a number of cell-specific reference signal (CRS) REs **432**, used by the receiving station to measure channel conditions. These reference signal REs **432** are interspersed at predetermined locations throughout the control region **420** and among the data REs **436** in the data portion **430** of the subframe **410**, and correspond to a cell-specific (or common) reference signal (CRS).

Transmissions in LTE are dynamically scheduled in each subframe, where the base station transmits downlink assignments/uplink grants to certain wireless terminals (also known as user equipment, or UEs, in 3GPP terminology) via the physical downlink control channel (PDCCH). The PDCCHs are transmitted in the control region **420** of the OFDM signal, i.e., in the first OFDM symbol(s) of each subframe, and span all or almost all of the entire system bandwidth. A UE that has decoded a downlink assignment, carried by a PDCCH, knows which resource elements in the subframe that contain data aimed for that particular UE. Similarly, upon receiving an uplink grant, the UE knows which time-frequency resources it should transmit upon. In the LTE downlink, data is carried by the physical downlink shared channel (PDSCH) and in the uplink the corresponding channel is referred to as the physical uplink shared channel (PUSCH).

LTE also employs multiple modulation formats, including at least QPSK, 16-QAM, and 64-QAM, as well as advanced coding techniques, so that data throughput may be optimized for any of a variety of signal conditions. Depending on the signal conditions and the desired data rate, a suitable combination of modulation format, coding scheme, and bandwidth is chosen, generally to maximize the system throughput. Power control is also employed to ensure acceptable bit error rates while minimizing interference between cells. In addition, LTE uses a hybrid-ARQ (HARQ) error correction protocol where, after receiving downlink data in a subframe, the terminal attempts to decode it and reports to the base station whether the decoding was successful (ACK) or not (NACK). In the event of an unsuccessful decoding attempt, the base station can retransmit the erroneous data.

LTE offers the possibility of transmitting Multicast and Broadcast over a Single Frequency Network (MBSFN), in which a time-synchronized common waveform is transmitted from multiple cells for a given duration. MBSFN transmission can be highly efficient, allowing for over-the-air combining of multi-cell transmissions in the UE while appearing to the UE as a transmission from a single large cell. Use of MBSFN can improve received signal strength, and can eliminate inter-cell interference.

SUMMARY

In heterogeneous networks, interference in low-power cells is dominated by interference from macro cells. Some macro cells use Almost Blank Subframes (ABS), which omit control and data resource elements, and include only cell-specific (or common) reference signal (CRS) resource elements (REs), to minimize their transmissions to wireless terminals supported by a low-power cell. As will be described below, blind detection methods are disclosed that analyze the interference from an ABS to determine if a macro cell is operating in a MBSFN or non-MBSFN mode.

In one embodiment, a method for detecting an ABS configuration for an interfering macro cell of a heterogeneous network is implemented in a wireless terminal. For one or more resource blocks in a received signal, a first power metric is calculated as a function of channel response estimates determined for predicted CRS RE locations in a plurality of symbols of the ABS. For the one or more resource blocks in the received signal, a second power metric is calculated as a function of channel response estimates determined for the predicted CRS RE locations in a single one of the plurality of symbols. A difference between the first and second power metrics is compared to a threshold, and responsive to the comparison a determination is made as to whether the macro cell is operating in a MBSFN mode or a non-MBSFN mode. In one example, the MBSFN mode corresponds to the difference being greater than or equal to the threshold, and the non-MBSFN mode corresponds to the difference being less than the threshold.

The determination of whether the macro cell is operating in the MBSFN mode may be used, along with a determination of whether the CRS REs from the interfering macro cell and a low-power cell within the macro cell are colliding or non-colliding, to determine at least one of a demodulation algorithm or a channel feedback algorithm for the wireless terminal.

In a corresponding apparatus embodiment, a wireless terminal for use in a heterogeneous wireless communication network includes one or more transceivers operative to transmit messages to and receive messages from an interfering macro cell and a low-power cell in the heterogeneous wireless communication network. A processing circuit is operatively associated with the one or more transceivers and includes a first power metric calculator, a second power metric calculator, a power metric comparer, and a macro cell mode determiner.

The first power metric calculator is configured to calculate, for one or more resource blocks in a received signal, a first power metric as a function of channel response estimates determined for predicted CRS RE locations in a plurality of symbols. The second power metric calculator is configured to calculate, for the one or more resource blocks in the received signal, a second power metric as a function of a channel response estimates determined for the predicted CRS RE locations in a single one of the plurality of symbols. The power metric comparer is configured to compare a difference between the first and second power metrics to a threshold. The macro cell mode determiner is configured to determine whether the macro cell is operating in a MBSFN mode or a non-MBSFN mode responsive to the comparison, with the MBSFN mode corresponding to the difference being greater than or equal to the threshold, and the non-MBSFN mode corresponding to the difference being less than the threshold.

The processing circuit of the wireless terminal may also include a collision detector configured to determine whether CRS REs from the interfering macro cell and a low-power cell within the macro cell are colliding or non-colliding, responsive to a received cell identifier from each of the macro cell and the low-power cell. An algorithm selector of the processing circuit may be configured to use the output of the macro cell mode determiner and the collision detector to determine at least one of a demodulation algorithm or a channel feedback algorithm for use in processing signals received from the low-power cell.

Of course, the present invention is not limited to the features and advantages summarized above. Indeed, those skilled in the art will recognize additional features and advan-

tages of the present invention upon reading the following detailed description and viewing the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates several picocells overlaid by a macro cell in a heterogeneous network.

FIG. **2** illustrates features of the OFDM time-frequency resource grid.

FIG. **3** illustrates the time-domain structure of an LTE signal.

FIG. **4** illustrates features of an LTE downlink subframe.

FIGS. **5***a-b* illustrate example subframes received from a low-power cell within a macro cell.

FIGS. **6***a-d* illustrate a plurality of example macro cell ABS subframes.

FIG. **7** illustrates how ABS detection can be used in connection with a traditional receiver.

FIG. **8** illustrates an example method for detecting an ABS configuration of a macro cell.

FIG. **9** illustrates the method of FIG. **8** with additional processing steps.

FIG. **10** illustrates an example implementation of a collision detection feature of the method of FIG. **9**.

FIG. **11** illustrates an example a wireless terminal operative to implement the methods of FIGS. **8-10**.

FIG. **12** illustrates a processing circuit of the wireless terminal of FIG. **11**.

DETAILED DESCRIPTION

Various embodiments of the present invention are now described with reference to the drawings, where like reference numerals are used to refer to like elements throughout. In the following description, numerous specific details are set forth for purposes of explanation, in order to provide a thorough understanding of one or more embodiments. It will be evident to one of ordinary skill in the art, however, that some embodiments of the present invention may be implemented or practiced without one or more of these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to facilitate describing embodiments.

Note that although terminology from 3GPP's specifications for LTE and LTE-Advanced (see, e.g., 3GPP TS 36.211 v10.3.0) is used throughout this document to exemplify the invention, this should not be seen as limiting the scope of the invention to only these systems. Other wireless systems including or adapted to include heterogeneous cell deployments may also benefit from exploiting the ideas covered herein.

Note also that the term "wireless terminal" as used in this application broadly refers to a device capable of wireless communicating with both a macro cell and a low-power cell. Thus, as described above, the wireless terminal may correspond to a UE in an LTE network, a non-LTE mobile terminal, or even a stationary wireless communication device such as a Machine-Type Communication (MTC) device.

Demodulation of transmitted data generally requires estimation of the radio channel over which the data is received. In LTE systems, this is done using transmitted reference symbols (RS), i.e., transmitted symbols having values that are already known to the receiver. In LTE, these reference symbols may correspond to the cell-specific CRS REs that are transmitted in all downlink subframes. In addition to assisting with downlink channel estimation, the CRS REs are also used for mobility measurements performed by the wireless terminals.

The CRS REs are generally intended for use by all the wireless terminals in the coverage area. To support improved channel estimation, especially when multiple-input multiple-output (MIMO) transmission techniques are used, LTE also supports UE-specific RS, which are targeted to individual wireless terminals and are intended specifically for channel estimation for demodulation purposes.

FIG. **4** illustrates how the mapping of physical control/data channels and signals can be done on resource elements within a downlink subframe **410**. In the pictured example, the PDCCHs occupy only the first out of the three possible OFDM symbols that make up the control region **420** (i.e. the leftmost OFDM symbol in FIG. **4**), so in this particular case the mapping of data can begin at the second OFDM symbol. Since the CRS are common to all UEs in the cell, the transmission of CRS cannot be easily adapted to suit the needs of a particular UE. This is in contrast to the UE-specific RS (not shown in FIG. **4**), by means of which each UE can have RS of its own placed in the data region **430** of FIG. **4**, as part of the PDSCH.

The length (one, two, or three symbols) of the control region **420** that is used to carry PDCCH can vary on a subframe-to-subframe basis, and is signaled to the wireless terminal in the Physical Control Format Indicator CHannel (PCFICH). The PCFICH is transmitted within the control region **420**, at locations known by terminals. Once a wireless terminal has decoded the PCFICH, it then knows the size of the control region **420** and also knows the OFDM symbol in which data transmission starts. Also transmitted in the control region **420** is the Physical Hybrid-ARQ Indicator Channel. This channel carries ACK/NACK responses to a terminal, to inform the wireless terminal whether the uplink data transmission in a previous subframe was successfully decoded by the base station.

FIG. **5** illustrates a downlink subframe **510** from a low-power cell **120** (e.g. a picocell). Like the subframe **410**, the subframe **510** includes a control region **520**, and a data region **530**. The control region **520** is used to transmit control resource elements **534** (e.g. via the PDCCH, PCFICH, and/or Physical Hybrid ARQ Indicator CHannel or "PHICH"). The data region **530** is used to transmit data resource elements **536** (e.g. via the PDSCH). Both the control region **520** and the data region **530** are used to transmit cell-specific CRS REs **532**.

In LTE networks, for example, 1, 2 or 4 antenna ports may be used by a transmitting cell. If the macro cell **110** and low-power cell **120** utilize multiple antenna ports, certain ones of the CRS REs may be used for each port. For example, FIG. **5***a* illustrates a subframe **510** in which one port is used, such that all CRS REs **532** apply to the single port. FIG. **5***b*, however, illustrates a subframe **510'** cells utilizing a two port configuration. In the subframe **510'**, half of the CRS REs **532***a* correspond to a first of the two ports, and the other half of the CRS REs **532***b* correspond to a second of the two ports. Of course, other quantities of ports could also be used.

In heterogeneous networks **100**, interference in picocells **120** is dominated by interference from macro cells **110**. Some macro cells may minimize their transmissions to wireless terminals supported by a picocell by transmitting reference symbols to those wireless terminals using an Almost Blank Subframe (ABS). An ABS omits control and data elements that would otherwise be included in a downlink subframe, and includes only the CRS REs **432** that are common to both ABS and non-ABS transmissions.

Whether the macro cell **110** is operating a MBSFN mode, and also whether the CRS REs of the macro cell and a low-power cell within the macro cell are colliding, can affect the interference experienced by a wireless terminal. As will be described below, the interference from an ABS may be analyzed to determine if the interfering macro cell is operating in a MBSFN or a non-MBSFN mode.

FIGS. **6***a-d* illustrate a plurality of example macro cell ABS subframes, each ABS including one resource block corresponding to fourteen OFDM symbols, and including only CRS REs **670** and blanked REs **680**. The blanked REs **680** are empty and without any content.

Referring to FIG. **6***a*, the ABS **610** includes CRS REs **670** in the first, fifth, eighth, and twelfth OFDM symbols of the ABS **610**, indicating that the macro cell **110** transmitting the ABS **610** is operating in a non-MBSFN mode. Additionally, within each OFDM symbol, the CRS REs **670** are offset from the CRS REs **532** of the low-power downlink subframe **510** (see FIGS. **5***a-b*), indicating that the CRS REs **670** of the ABS **610** are non-colliding with respect to the CRS REs **532** of the subframe **510**.

Referring to FIG. **6***b*, the ABS **620** includes CRS REs **670** only in a single OFDM symbol, indicating that the macro cell **110** transmitting the ABS **620** is operating in the MBSFN mode. As with the ABS **610**, the CRS REs **670** are offset from the CRS REs **532** of the downlink subframe **510** (see FIG. **5**), indicating that the CRS REs **670** of the ABS **610** are non-colliding with respect to CRS REs **532** of the subframe **510**.

Referring to FIGS. **6***c* and **6***d*, the CRS REs **670** of each illustrated ABS **630**, **640** are aligned with the CRS REs **532** of the downlink subframe **510** (see FIG. **5**), indicating that the ABS **630**, and the ABS **640** are colliding with the downlink subframe **510**. Regarding the ABS **630** specifically, because the CRS REs **670** span across multiple OFDM symbols, the macro cell **110** transmitting the ABS **630** is operating in the non-MBSFN mode. Regarding the ABS **640** specifically, because the CRS REs **670** span across only a single OFDM symbol, the macro cell **110** transmitting the ABS **640** is operating in the MBSFN mode.

Each of these configurations exhibits different interference characteristics. Thus, each configuration corresponds to a different optimal demodulation process and/or interference processing approach. For example, if a macro cell is transmitting the ABS **610** of FIG. **6***a* (non-MBSFN/non-colliding CRS REs), the CRS REs **532** of the picocell are clean without any interference. However, some of the data REs **536** (sent via the PDSCH) may experience severe interference by the CRS REs **670** of macro cells. Thus, it may be desirable for a wireless terminal to compensate or puncture on the data REs **536** to improve demodulation performance. Furthermore, it may be desirable for the wireless terminal to adjust channel quality measurements by taking such interference into account to improve link adaptation performance.

If a macro cell is transmitting the ABS **620** of FIG. **6***b* (MBSFN/non-colliding CRS REs), the CRS REs **532** of the low-power are clean without any interference. However, some of the control REs **534** (sent via the PDCCH) experience interference because of the CRS REs **670** of the macro cell. In this scenario, it may be desirable to process the polluted REs (i.e. the REs of the control region **520** of subframe **510** which are experiencing collisions) in a special way, such as setting corresponding soft values to zero.

If a macro cell is transmitting the ABS **630** of FIG. **6***c* (non-MBSFN/colliding CRS REs), the CRS REs **670** interfere with all of the CRS REs **532** of the downlink subframe **510**. However, in this scenario the data REs **536** are totally clean without any interference. In such a scenario, CRS cancellation algorithms can be implemented to improve the accuracy of channel estimation. Furthermore, when calculating Channel Quality Indicator (CQI)/Precoding Matrix Indicator (PMI)/Rank Indicator (RI), it may be desirable to compensate for the power offset between the CRS REs and PDSCH data REs **536** to improve link adaptation performance.

If a macro cell is transmitting the ABS **640** of FIG. **6***d* (MBSFN/colliding CRS REs), the CRS REs **532** in the data region **530** of the subframe **510** are clean, but the CRS REs **670** of the ABS **640** interfere with the CRS REs **532** in the control region **520**, which results in different interference level for the CRS REs **532**. In such a scenario, it would be desirable for control channel demodulation to estimate the radio channel from the CRS REs **532** in the control region **520**, and for data channel demodulation (e.g. the PDSCH) it would be desirable to estimate the radio channel from the CRS REs **532** in the data region **530**. Furthermore, it may be desirable to calculate the CQI/PMI/RI from the radio channel measured from the CRS REs **532** in the data region **530**.

Although the example almost blank subframes **610-640** (see FIGS. **6***a-b*) and the low-power cell subframe **510** (see FIG. **5***a*) are illustrated separately, it is understood that these subframes will be overlayed on top of each other when received at a wireless terminal, with the ABS **610-640** representing interference from the macro cell **110**. Thus, the control region **520** of the subframe **510** also refers to the same region of each ABS of FIGS. **6***a-d*. Similarly, the data region **530** of the subframe **510** also refers to the same region of each ABS of FIGS. **6***a-d*.

Methods for detecting both the macro cell operating mode (MBSFN/non-MBSFN) and CRS RE configuration (colliding or non-colliding) in a heterogeneous network are discussed below in detail, which methods enable a wireless terminal to optimize demodulation and/or interference processing based on this information. A wireless terminal **900** configured to implement those methods is also disclosed (see FIG. **11**).

The ABS detection methods described below constitute "blind detection" methods, in that they may be performed prior to traditional receiver procedures such as CQI/PMI/RI calculation, channel estimation, and demodulation. These blind ABS detections may be based on a difference in Reference Signal Received Power (RSRP) of the CRS REs between the control region **520** and data region **530**. Additionally, by using a cell ID of the macro cell **110** and the low-power cell **120**, a determination can be made as to whether the CRS REs of the ABS and downlink subframe **510** are colliding or non-colliding.

Referring to FIG. **7**, a signal processing block diagram **700** is shown, which utilizes channel estimation **710**, CQI/PMI/RI calculation **720**, demodulation **730**, and decoding **740**. As shown in FIG. **7**, and as will be discussed below in greater detail, the inclusion of ABS configuration blind detection **760** can improve both CQI/PMI/RI calculation **720** and demodulation **730**.

FIG. **8** illustrates an example method **800** for detecting an ABS configuration for an interfering macro cell in a heterogeneous network (e.g. the macro cell **110** in the heterogeneous network **100**). The method **800** is implemented in the wireless terminal **900** of FIG. **11**. For one or more resource blocks in a received signal, the wireless terminal **900** calculates (step **810**) a first power metric as a function of channel response estimates determined for predicted CRS RE locations in a plurality of symbols (e.g. OFDM symbols). For the one or more resource blocks in the received signal, the wireless terminal **900** also calculates (step **820**) a second power

metric as a function of channel response estimates determined for the predicted CRS RE locations in a single one of the plurality of symbols.

A difference between the first and second power metrics is compared (step **830**) to a threshold, and responsive to the comparison a determination is made (step **840**) as to whether the macro cell is operating in a MBSFN mode or a non-MBSFN mode. In one example, the MBSFN mode corresponds to the difference being greater than or equal to the threshold, and the non-MBSFN mode corresponds to the difference being less than the threshold.

Although only a single ABS is illustrated in each of FIGS. **6***a-d* (each including a single resource block) and only a single low-power cell subframe **510** is illustrated in FIGS. **6***a-b* (also each including a single resource block), it is understood that multiple resource blocks could be analyzed. Thus, in one example, the steps of calculating a first power metric (step **810**), calculating a second power metric (step **820**), and comparing a difference between the first and second power metrics to a threshold (step **830**) are performed for a plurality of resource blocks. In this example, the determining of whether the macro cell is operating in a MBSFN mode or a non-MBSFN mode (step **840**) is performed responsive to the plurality of comparisons, with the MBSFN mode corresponding to a majority of the differences being greater than or equal to the threshold, and the non-MBSFN mode corresponding to a majority of the differences being less than the threshold.

FIG. **9** illustrates the method **800** of FIG. **8** with additional processing steps. In a first step, CRS RE locations are predicted (step **802**) for the received ABS and the low-power cell subframe **510**, responsive to a cell identifier (ID) received from each of the macro cell **110** and the low-power cell **120**. Step **802** includes predicting the CRS RE locations for the plurality of symbols of step **810** (e.g. the first, fifth, eighth and twelfth OFDM symbols) and the single one of the plurality of symbols of step **820** (e.g. the first OFDM symbol of the ABS).

For one or more resource blocks in a received signal, a first power metric is calculated (step **810**) as a function of channel response estimates determined for predicted CRS RE locations in a plurality of symbols. The first power metric is calculated under the hypothesis that the interfering macro cell **110** is operating in the non-MBSFN mode (in which case CRS REs are included in a plurality of OFDM symbols of the ABS).

The first power metric may correspond to a reference signal received power (RSRP) for the CRS. In one example, the RSRP may be calculated differently for the control region (region **520**), and the data region (region **530**). The control region RSRP (CR-RSRP) may be defined as the linear average over the power contributions (in Watts) of the CRS REs within the considered measurement frequency bandwidth in the OFDM symbols used for PDCCH/PCFICH/PHICH allocation (i.e. the control region **520**). The data region RSRP (DR-RSRP) may be defined as the linear average over the power contributions (in Watts) of the CRS REs within the considered measurement frequency bandwidth in the OFDM symbols used for PDSCH allocation (i.e. the data region **530**).

Step **810** may be implemented using equation #1 shown below:

$$P_0^{(p)} = \frac{1}{N_{RB}} \sum_{RB=0}^{N_{RB}-1} \left|\bar{h}_{0,RB}^{(p)}\right|^2 \qquad \text{equation \#1}$$

In equation #1, p refers to a CRS port number, and K corresponds to the quantity of CRS REs for each port p in an l^{th} OFDM symbol within a given resource block. Thus, for example, if one port is being used, then for each OFDM symbol including a CRS RE, four REs are included for the single port, so K=2 (see, e.g., FIG. **5***a*). Similarly, if two ports are being used, then for each OFDM symbol including a CRS RE, two REs are included for each port, so the value of K=2 (see, e.g., FIG. **5***b*).

The variable N_{RB} corresponds to the number of resource blocks being considered. Thus, N_{RB} effectively defines the frequency bandwidth being analysed by the wireless terminal **900** in performing method **800**. As discussed above, while it is possible that a single received resource block may be analysed (see, e.g., the single resource block pictured in each of FIGS. **5***a-b* and FIGS. **6***a-d*), it is understood that the method **800** is not limited to only covering one resource block, and that multiple simultaneously-received, or subsequently-received resource blocks could be considered. In one example, N_{RB}=50, indicating that 50 received resource blocks are being analysed, which may correspond to a 10 MHz measurement frequency bandwidth.

The $\bar{h}_{0,RB}^{(p)}$ of equation #1 is the average channel estimate for the RB^{th} resource block, and may be computed as follows:

$$\bar{h}_{0,RB}^{(p)} = \frac{1}{KL_0} \sum_{k=0}^{K-1} \sum_{l\in\{0,4,7,11\}} \frac{r_{l,k,RB}^{(p)}}{v_{l,k,RB}^{(p)}} \qquad \text{equation \#2}$$

In this equation, $r_{l,k,RB}^{(p)}$ denotes the received complex value for the l^{th} OFDM symbol of, and the k^{th} CRS RE within an RB^{th} resource block. The variable $v_{l,k,RB}^{(p)}$ is equal to the pilot value for the same RE.

The variable L_0 is equal to the number of symbols that contains CRS REs in the case of the non-MBSFN ABS (e.g. L_0=4 to account for the first, fifth, eighth, and twelfth symbols of ABS **610**). If the wireless terminal **900** knows the quantity, N_{CRS}, of CRS ports being utilized by the low-power cell **120** from the physical broadcasting channel (PBCH), the power can be averaged as shown below:

$$P_0 = \frac{1}{N_{CRS}} \sum_{p=0}^{N_{CRS}-1} P_0^{(p)} \qquad \text{equation \#3}$$

Alternatively, if the quantity of CRS ports is not known, the equation #4 (shown below) may be used to determine power. In order to obtain P_0 in Watts, it may be necessary to perform scaling with an appropriate factor.

$$P_0 = P_0^{(0)} \qquad \text{equation \#4}$$

Referring again to FIG. **9**, for the one or more resource blocks in the received signal, a second power metric is calculated (step **820**) as a function of channel response estimates determined for the predicted CRS RE locations in a single one of the plurality of symbols. Thus, the second power metric is calculated under the hypothesis that the macro cell **110** is operating in the MBSFN mode (in which case CRS REs are included only in a single OFDM symbol of the ABS). Step **820** may be implemented using equations #5-6 shown below:

$$P_1^{(p)} = \frac{1}{N_{RB}} \sum_{RB=0}^{N_{RB}-1} |\bar{h}_{1,RB}^{(p)}|^2 \quad \text{equation \#5}$$

$$\bar{h}_{1,RB}^{(p)} = \frac{1}{KL_1} \sum_{k=0}^{K-1} \sum_{l \in [0]} \frac{r_{l,k,RB}^{(p)}}{v_{l,k,RB}^{(p)}} \quad \text{equation \#6}$$

In these equations, L_1=1 corresponds to the number of OFDM symbols that contains CRS REs in the MBSFN subframe case (see, e.g., ABS **620** and ABS **640**). If number of CRS ports are known, one may use equation #7, and if not one may use equation #8, both shown below.

$$P_1 = \frac{1}{N_{CRS}} \sum_{p=0}^{N_{CRS}-1} P_1^{(p)} \quad \text{equation \#7}$$

$$P_1 = P_1^{(0)} \quad \text{equation \#8}$$

Referring again to FIG. **9**, a difference between the first and second power metrics is determined (see equation #9 below), and that difference is compared to a threshold P_{thrd} (step **830**).

$$\Delta P = P_1 - P_0 \quad \text{equation \#9}$$

The threshold P_{thrd} may be a power threshold, and in one or more embodiments may be predetermined. Of course, it is also possible that the threshold may be dynamically determined. Responsive to the comparison of step **830**, a determination is made (step **840**) as to whether the macro cell **110** is operating in the MBSFN mode or the non-MBSFN mode. In one example, the MBSFN mode corresponds to the difference being greater than or equal to the threshold (i.e., $\Delta P \geq P_{thrd}$), and the non-MBSFN mode corresponds to the difference being less than the threshold (i.e., $\Delta P < P_{thrd}$).

A determination may then be made (step **850**) as to whether CRS REs from the macro cell **100** and the low-power cell **120** within the macro cell **110**, are colliding or non-colliding responsive to a cell identifier (ID) received from each of the macro cell **110** and the low-power cell **120**.

FIG. **10** illustrates an example implementation of step **850** in greater detail. In the example of FIG. **10**, step **850** includes determining a cell ID (step **852**) for each of the macro cell **110** and the low-power cell **120**. These cell IDs may be labeled $cell_id_0$ and $cell_id_1$ respectively. Step **852** may be performed via a cell search performed over a primary synchronization signal (PSS), a secondary synchronization signal (SSS), or both, for example.

An integer value is selected (step **854**) responsive to the quantity of antenna ports used by the macro cell **110**, the low-power cell **120**, or both (e.g. "6" in a one port setup, or "3" in a two or more port setup). Then, a determination is made (step **856**) as to whether the difference between the cell IDs is a multiple of the integer value, or is not a multiple of the integer value. In one example, if the difference is a multiple of the integer value then the CRS REs of the ABS and subframe **510** are determined to be colliding, and if the difference is not a multiple of the integer value then the CRS REs of the ABS and subframe **510** are determined to not be colliding.

Step **856** may include use of the modulo operation. Thus, for example, if mod ($cell_id_1$-$cell_id_0$, 6)=0 in one port setup or mod ($cell_id_1$-$cell_id_0$, 3)=0 in two or more CRS port setup, the CRS REs are colliding, and if neither one of these expression equals zero then the CRS REs are as non-colliding.

Returning now to FIG. **9**, once steps **840** and **850** have been performed, another determination is made (step **860**) of at least one of a demodulation algorithm or a channel feedback algorithm for the wireless terminal **900** responsive to the determination of whether the macro cell **110** is operating in the MBSFN mode or the non-MBSFN mode (step **840**), and the determination of whether the CRS REs of the ABS and the low-power cell subframe are colliding or non-colliding (step **850**).

The determined demodulation algorithm may include an advanced receiving algorithm, such as PDSCH demodulation or PDCCH demodulation. The determined channel feedback algorithm may be a CQI/PMI/RI measurement algorithm. Some example algorithm selection criteria are summarized in the Table 1 below. In Table 1, the phrase "aggressive cell" refers to the interfering macro cell **110**, and the phrase "polluted REs" refers to the CRS REs of the control region **520** of subframe **510** which are experiencing collisions.

TABLE 1

Advanced algorithms to be used following ABS detection

ABS	CQI/PMI/RI calculation	PDSCH demodulation	PDCCH demodulation
ABS 610	The impact of polluted REs from the aggressive cell should be involved to determine CQI/PMI/RI for link adaptation.	The interference on the polluted REs from the aggressive cell can be estimated and compensated.	The interference on the polluted REs from the aggressive cell can be estimated and compensated.
ABS 620	The CQI/PMI/RI should be calculated from the CRS REs in the data channel region 530.	The channel used to assist demodulation should be estimated from the CRS REs in the data channel region 530.	The interference on the polluted REs from the aggressive cell can be estimated and compensated.
ABS 630	The interference offset between CRS and PDSCH REs should be involved to determine the CQI/PMI/RI.	The interference to CRS REs from the aggressive cell can be estimated and cancelled.	The interference to CRS REs from the aggressive cell can be estimated and cancelled.
ABS 640	The CQI/PMI/RI should be calculated from the CRS REs in the data channel region 530.	The channel used to assist demodulation should be estimated from the CRS REs in the data channel region 530.	The channel used to assist demodulation should be estimated from the CRS REs in the control channel region 520.

FIG. **11** illustrates an example wireless terminal **900** configured to carry out the methods of FIGS. **8-1** in a heterogeneous network. Of course, not every detail of the wireless terminal **900** design is shown, but instead a few of the components relevant to the present techniques are pictured. The pictured wireless terminal **900** includes a transceiver circuit **902** and a processing circuit **904**. The transceiver circuit **902** includes one or more receiver circuits and transmitter circuits that use known radio processing and signal processing components and techniques, typically according to a particular telecommunications standard such as the 3GPP standard for LTE and/or LTE-Advanced. Because the various details and engineering tradeoffs associated with the design and implementation of such circuitry are well known and are unnecessary to a full understanding of the invention, additional details of the transceiver circuit **902** are not shown here.

The processing circuit **904** includes a processor **906** configured to implement the methods of FIGS. **8-10** by for example executing program code stored in memory **908**. The processor **906** may include, for example, a combination of one or more microprocessors or microcontrollers, digital signal processors (DSPs), special-purpose digital logic, and the like. The memory **908** may include one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc. The memory **908** includes program instructions for executing one or more telecommunications and/or data communications protocols, as well as instructions for carrying out one or more of the methods described above.

FIG. **12** illustrates the processing circuit **904** of the wireless terminal **900** of FIG. **10** in greater detail. As shown in FIG. **12**, the processing circuit **904** may include a first power metric calculator **910** (for performing step **810**), a second power metric calculator **912** (for performing step **820**), a power metric comparer **914** (for performing step **830**), and a macro cell mode determiner **916** (for performing step **840**). The processing circuit **904** may also include a CRS RE location predictor **918** (for performing step **802**), a collision detector **920** (for performing step **850**), and an algorithm selector **922** (for performing step **860**). The various modules **910-922** of the processing circuit may correspond to separate circuits, or may correspond to a single circuit (e.g. a microprocessor), for example. Of course, it will be appreciated that not all of the steps **802-860** are necessarily performed in a single microprocessor or a single module.

Advantageously the methods of FIGS. **8-10** may be used to implement a blind ABS detection to assist in algorithm selection. By measuring the difference between control region **520** RSRP and data region **530** RSRP, the wireless terminal **900** can detect an ABS configuration of the interfering macro cell **110**, and can use that detected configuration along with a detection of whether the CRS REs are colliding or non-colliding, in selecting a demodulation or channel feedback algorithm. Also, the difference between the powers of CRS REs in data region **530** and control region **520** may be calculated as the residual interference to assist CQI compensation.

Examples of several embodiments of the present invention have been described in detail above, with reference to the attached illustrations of specific embodiments. Because it is not possible, of course, to describe every conceivable combination of components or techniques, those skilled in the art will appreciate that the present invention can be implemented in other ways than those specifically set forth herein, without departing from essential characteristics of the invention. The present embodiments are thus to be considered in all respects as illustrative and not restrictive.

The invention claimed is:

1. A method for detecting an Almost-Blank Subframe (ABS) configuration for an interfering macro cell of a heterogeneous network, the method being implemented in a wireless terminal and comprising:

for one or more resource blocks in a received signal that is received from a cell in the heterogeneous network that is not the interfering macro cell, calculating a first power metric as a function of channel response estimates determined for predicted common reference signal (CRS) resource element locations in a plurality of symbols;

for the one or more resource blocks in the received signal, calculating a second power metric as a function of channel response estimates determined for the predicted CRS resource element locations in a single one of the plurality of symbols;

comparing a difference between the first and second power metrics to a threshold; and

determining whether the interfering macro cell is operating in a Multicast and Broadcast Single Frequency Network (MBSFN) mode or a non-MBSFN mode based on the comparison, wherein the MBSFN mode corresponds to the difference being greater than or equal to the threshold, and the non-MBSFN mode corresponds to the difference being less than the threshold.

2. The method of claim **1**:

wherein calculating a first power metric, calculating a second power metric, and comparing a difference between the first and second power metrics to a threshold are performed for a plurality of resource blocks; and

wherein determining whether the interfering macro cell is operating in a MBSFN mode or a non-MBSFN mode is performed based on the plurality of comparisons, with the MBSFN mode corresponding to a majority of the differences being greater than or equal to the threshold, and the non-MBSFN mode corresponds to a majority of differences being less than the threshold.

3. The method of claim **1**, wherein the plurality of symbols corresponds to the first, fifth, eighth and twelfth symbols of the one or more resource blocks, and wherein the single one of the plurality of symbols corresponds to the first symbol of the one or more resource blocks.

4. The method of claim **1**, further comprising predicting the CRS resource element locations for the plurality of symbols and the single one of the plurality of symbols based on a cell identifier (ID) received from each of the interfering macro cell, and a low-power cell supporting the wireless terminal.

5. The method of claim **1**, wherein the cell in the heterogeneous network that is not the interfering macro cell is a low-power cell, the method further comprising determining whether CRS resource elements from the interfering macro cell and the low-power cell within the macro cell are colliding or non-colliding based on a cell identifier (ID) received from each of the macro cell and a low-power cell.

6. The method of claim **5**, further comprising determining at least one of a demodulation algorithm or a channel feedback algorithm for the wireless terminal based on the determination of whether the interfering macro cell is operating in the MBSFN mode or the non-MBSFN mode, and the determination of whether the CRS resource elements are colliding or non-colliding.

7. The method of claim **5**, wherein the determining whether CRS resource elements from the interfering macro cell and the low-power cell within the macro cell are colliding or non-colliding based on a cell ID received from each of the interfering macro cell and the low-power cell comprises:

performing a cell search to determine the cell ID for each of the macro cell and the low-power cell; and

determining if a difference between the cell IDs is a multiple of a integer value, wherein the CRS resource elements being colliding corresponds to the difference being a multiple of the integer value, and wherein the CRS resource elements being non-colliding corresponds to the difference between the cell IDs not being a multiple of the integer value.

8. The method of claim **7**, further comprising:

selecting the integer value based on a quantity of antenna ports being utilized by the macro cell, the low-power cell, or both.

9. The method of claim **7**, wherein the cell search is performed over a primary synchronization signal (PSS), a secondary synchronization signal (SSS), or both.

10. A wireless terminal for use in a heterogeneous wireless communication network, the wireless terminal comprising:

a one or more transceivers operative to transmit messages to and receive messages from an interfering macro cell and a low-power cell in the heterogeneous wireless communication network; and

a processing circuit operatively associated with the one or more transceivers, and configured as:

a first power metric calculator configured to calculate, for one or more resource blocks in a received signal that is received from the low-power cell, a first power metric as a function of channel response estimates determined for predicted common reference signal (CRS) resource element locations in a plurality of symbols;

a second power metric calculator configured to calculate, for the one or more resource blocks in the received signal, a second power metric as a function of channel response estimates determined for the predicted CRS resource element locations in a single one of the plurality of symbols;

a power metric comparer configured to compare a difference between the first and second power metrics to a threshold; and

a macro cell mode determiner configured to determine whether the interfering macro cell is operating in a Multicast and Broadcast Single Frequency Network (MBSFN) mode or a non-MBSFN mode based on the comparison, wherein the MBSFN mode corresponds to the difference being greater than or equal to the threshold, and the non-MBSFN mode corresponds to the difference being less than the threshold.

11. The wireless terminal of claim **10**, wherein the power metric comparer is configured to compare differences between the first and second power metrics of a plurality of resource blocks, and wherein the MBSFN mode corresponds to a majority of the differences being greater than or equal to the threshold, and the non-MBSFN mode corresponds to a majority of differences being less than the threshold.

12. The wireless terminal of claim **10**, wherein the plurality of symbols corresponds to the first, fifth, eighth and twelfth symbols of the one or more resource blocks, and wherein the single one of the plurality of symbols corresponds to the first symbol of the one or more resource blocks.

13. The wireless terminal of claim **10**, wherein the processing circuit is further configured as a CRS resource element location predictor configured to predict the CRS resource element locations for the plurality of symbols and the single one of the plurality of symbols based on a cell identifier (ID) received from each of the macro cell and the low-power cell.

14. The wireless terminal of claim **10**, wherein the processing circuit is further configured as a collision detector configured to determine whether CRS resource elements from the macro cell and the low-power cell within the macro cell are colliding or non-colliding based on a cell identifier (ID) received from each of the macro cell and the low-power cell.

15. The wireless terminal of claim **14**, wherein the processing circuit is further configured as an algorithm selector configured to determine at least one of a demodulation algorithm or a channel feedback algorithm for use in processing the received signal based on the determined macro cell mode and the determination of whether the CRS resource elements are colliding or non-colliding.

16. The wireless terminal of claim **14**, wherein to determine whether the CRS resource elements from the macro cell and the low-power cell within the macro cell are colliding or non-colliding based on a cell ID received from each of the macro cell and the low-power cell, the collision detector is configured to:

perform a cell search to determine the cell ID for each of the macro cell and the low-power cell; and

determine if a difference between the cell IDs is a multiple of a integer value, wherein the CRS resource elements being colliding corresponds to the difference being a multiple of the integer value, and wherein the CRS resource elements being non-colliding corresponds to the difference between the cell IDs not being a multiple of the integer value.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,179,396 B2
APPLICATION NO. : 13/384440
DATED : November 3, 2015
INVENTOR(S) : Wang et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

In Column 11, Line 39, delete "macro cell 100" and insert -- macro cell 110 --, therefor.

Signed and Sealed this
Twenty-ninth Day of March, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office